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Cryocooled facilities for superconducting coils testing in gaseous helium.

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Abstract

Two superconducting coil test facilities equipped by Sumitomo SRDK-415D cryocoolers were developed, manufactured and tested. The motivation for their constructing was to make cheaper the testing (and especially training of LTS magnets) by liquid helium (LHe) saving. It is well known that the helium price increases rapidly and this tendency most probably will continue for a long time, as the demand of helium grows faster than its production. The utilization of heat-exchange gas considerably reduces many problems, that arise in the design of completely dry LTS magnets. The goal was to decrease or even completely avoid the consumption of rather expensive liquid helium for testing the laboratory size Nb-Ti and Nb_3Sn coils including their training process. Several superconducting magnets were tested by using these facilities. For example, the first facility was successfully used for testing of 13 T, 60 kg coil cooled by cryocooler in helium gas (several torr pressure) heat exchange atmosphere. The precooling time was about 45 hours. The quench current (240 A at 4.2 K) was equal to that reached in the pool boiling LHe cryostat. The second facility with 420 mm wide access bore can be used for testing of corresponding size superconducting coils with very modest consumption of liquid helium with its level well below the lower flange of the coil. Each test facility is equipped by 2 pairs of HTS current leads. Design and operational experience of one of them is described.

Keywords: cryocooler; supercunducting magnet; heat-exchange gas; quench current

1. Test facility design

It is well known that the helium price increases rapidly and this tendency most probably will continue for a long time, as the demand of helium grows faster than its production [1].

LHe temperature level can be easily reached nowadays by utilization of compact, reliable and easily maintained cryocoolers [2]. We have developed and manufactured the LTS magnets test facility based on Gifford-McMahon type Sumitomo Inc. SRDK-415D cryocoller with nominal parameters 45 W, 50 K at the 1-st stage and 1.5 W, 4.2 K at the 2-nd stage.

The design of the first test facility is shown in Fig. 1 (a) and (b).

The tested LTS coil was welded inside the stainless steel vessel. To change the coil the weld can be easily cut and then rewelded. The cold head of the cryocooler is immersed in the central tube of the vessel. Two other tubes are used for HTS current leads. In the second test facility the vessel with the coil under testing is surrounded with liquid nitrogen (LN_2) vessel. The usage of LN_2 was motivated by two reasons. First it is helpful for shorting the precooling time; secondly, it allows to stop the cryocooler operation for several days (weekends, holidays etc.) without full warming up. Typically stopping the operation Friday afternoon when the coil temperature is close to 4.2 K we can start the operation Monday morning from coil temperature about 90 K. The LN_2 shield is thermally connected to the

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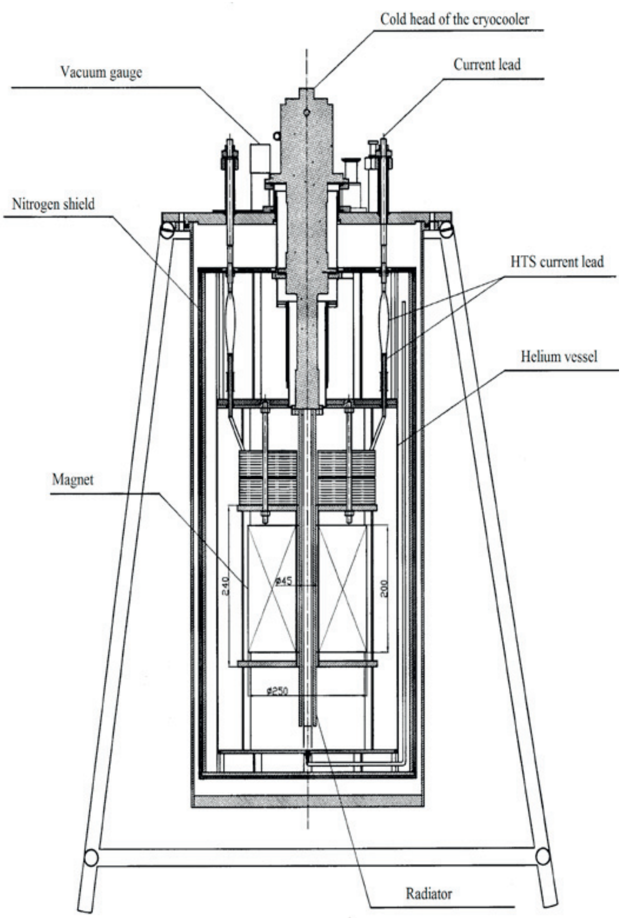
1st stage of the cryocooler through circular copper elastic elements. To minimize heat leaks from all necks they are anchored to the upper part of LN_2 vessel with flexible copper cables.



(a) (b)

Fig.1 (a) Photo of superconducting magnet with the cryocooler's cold head; (b) Drawing of the test facility

The upper part of current leads is made of brass strips, while in the lower part the 2G HTS tapes are used. The transition parts between normal and HTS sections of the current leads are thermally anchored to the upper copper plate at the shield with a proper electrical insulation. The current leads protrude into the LHe vessel using a tubular ceramic isolators vacuum-tightly glued to the Nb_3Sn rods. The upper part of the latter were soft soldered to HTS tapes.
Several pure copper bars are attached to the 4.2 K cryocooler disk to make easer temperature redistruction along the vessel height.

For the first testing an usual (Nb_3Sn+ NbTi) coil was used previously tested into LHe (ID= 45 mm, OD = 255 mm, winding height 220 mm). Total mass to be cooled down to 4.2 K was about 60 kg.

2. Test results

The facility was equipped with temperature sensors placed at both stages of the cooler, at upper and lower plates of the thermal shields, onto the surface of helium vessel, and onto the OD of the coil. One of the sensors was placed directly in the heat exchange gas. The initial pressure of the heat-exchange gas was 1 atm. All temperatures were measured continuously. The typical precooling process is shown in Fig.3.

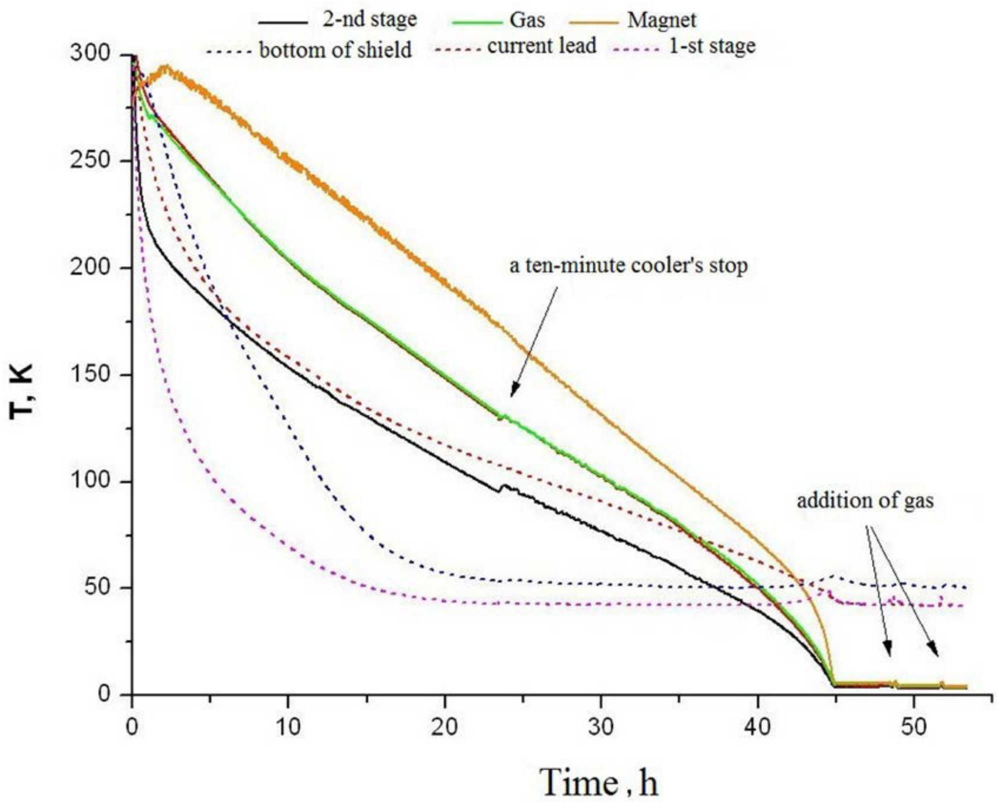


Fig.2 The cooling process from room temperature down to LHe temperature.

It is seen that the thermal shield was cooled down to 54 K in 26 hours, and the coil was cooled down to 4.2 K in 45 hours. During the cooling process the cooler was switched off for about 10 minuties to imitate an electrical fault. It is seen that the coil temperature practically did not change, while some increase of the 2nd stage temperature was observed.

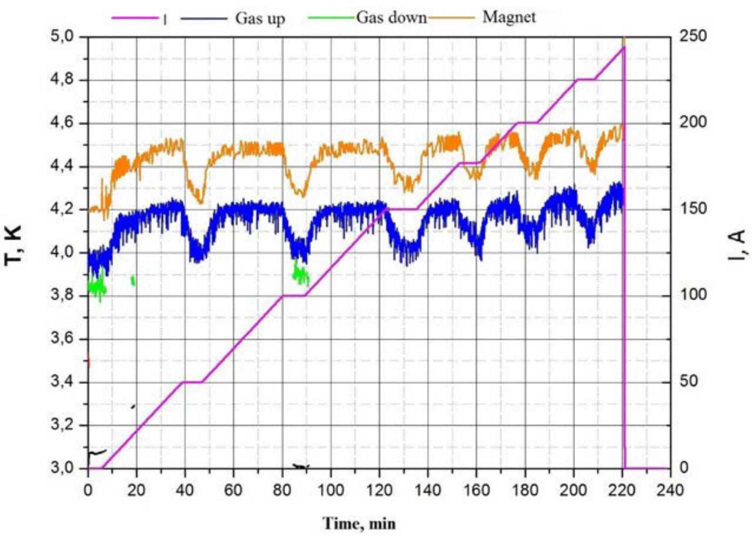
The cooling from room to LHe temperature was performed without adding the heat exchange helium and pressure was lowered to about 0.02 bar. After stopping the temperature decrease (at ~ 4.5 K) some (70 l.) GHe was added that resulted in further temperature decrease to about 4 K (decreased by 0.5 K). The second addition of the exchange gas resulted in further but very limited decrease of the coil temperature.

The current charging were accompanied with some coil and gas temperature increase. Therefore from time to time the charging was stopped to return the coil temperature to its starting value. Fig. 3 (a) shows the first charging of the coil. Up to 150 A the stops were done after each 50 K. At higher currents the 10 min stops were made after each 25 A. The quench current 240 A corresponded to 13 T central field. It is worthwhile to note that during previous test in the boiling LHe (about 10 years ago) the quench current was 240A too.

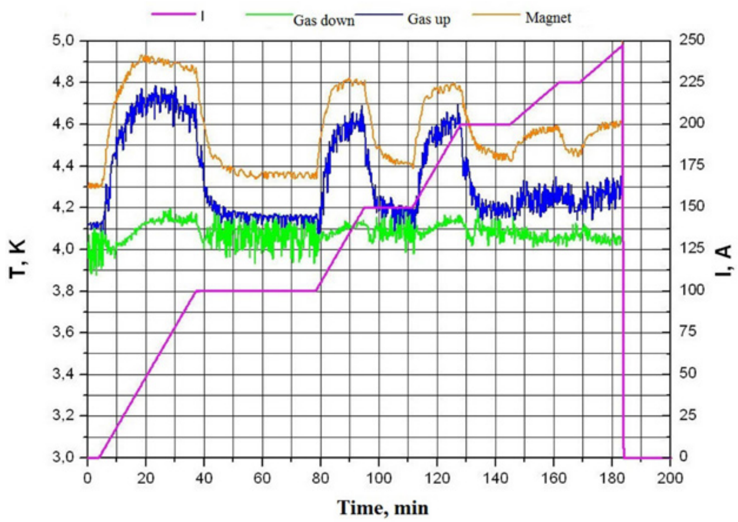
In the second charging (b) the coil was charged up to 100 A without any stops. Then after 25 min long stop the charging was continued. The next quench currents steadily increased (244 A; 247 A; 248 A)

The quenches were accompanied with heat-exchange gas temperature increase up to 70-80 K corresponding to the pressure rise up to 0.6 bar.

After the quench, the next charging was possible in 3.5-4 hours.



(a)



(b)

Fig.3 (a) First quench; (b) Second quench

3. Conclusions

It is demonstrated that testing of LTS coils not in LHe but in GHe does not result in lower quench currents. It opens the possibility of much cheaper testing process.

It is also important to note that this method does not require any special coil design (for example, increasing of the winding heat conductivity by inserting of copper mesh etc.)

We are sure that this approach is applicable and feasible to the tests of SC coils of much larger sizes, hopefully, up to whole body MRI dimensions.

References

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